LA-UR-19-25815
Approved for public release; distribution is unlimited.

Title: Special Purpose Reactors

Author(s): Mcclure, Patrick Ray

Intended for: Laboratory internal presentations

Issued: 2019-06-21

Special Purpose Reactors

Small fission reactors for space and defense applications

Patrick McClure
Los Alamos National Laboratory

2019

Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

75 Los Alamos NATIONAL LABORATORY EST.1943

PROUD LEGACY BOLD FUTURE SINCE 1943

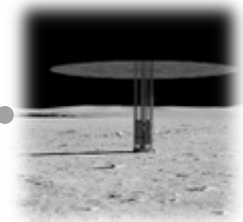
Focusing on established technologies and following the physics

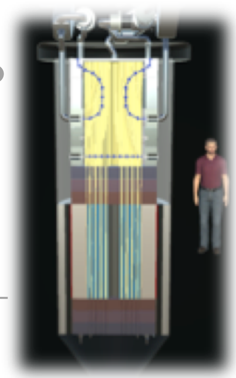
Original designs prioritized simplicity and ease of building/testing by combining existing technologies and following well-known nuclear physics, eliminating the need for complicated control systems

The **first tangible US advancement** for decades in fission energy - Demonstrated by the design, building, and successful testing of the first KiloPower prototype

Reactor design capabilities **leverage** weapons programs and decades of reactor design/testing **experience**

Game Changing **ENABELING** Technology



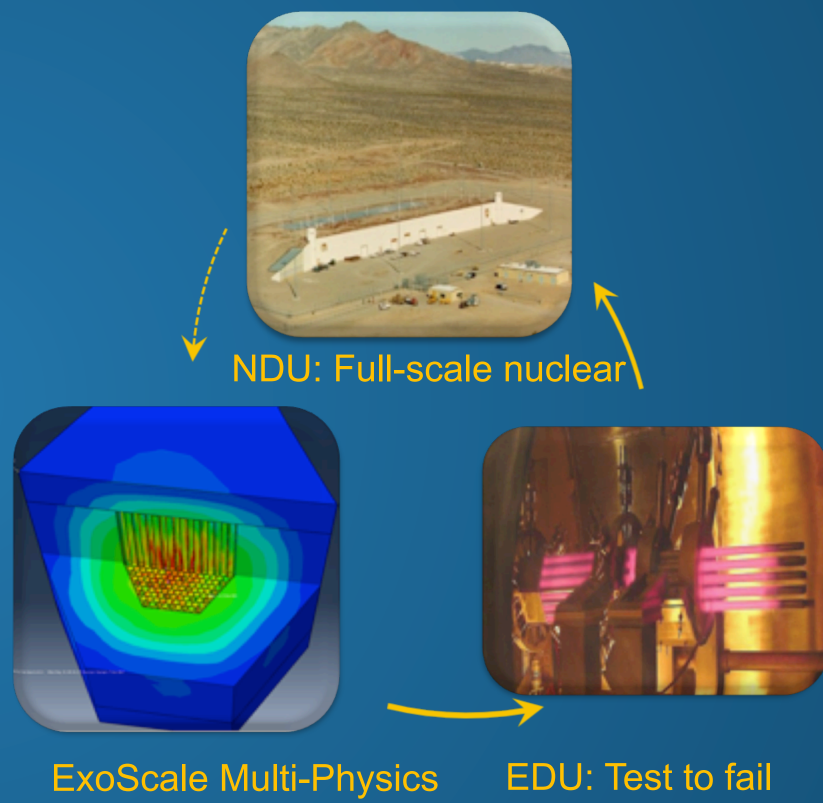


Successful Tests – confirmed predictive performance and validate base design assumptions

LANL has unique capabilities to DESIGN, BUILD, and TEST special purpose reactors

- LANL is using broad NNSA capabilities to make operational hardware
- Coupling decades of experience with the best computational and scientific tools
- Leveraging existing NNSA resources to provide relatively inexpensive design, computing evaluations, and testing
- With a long history of innovation in nuclear, space, and energy technologies; ***Los Alamos has the expertise to lead the transformation of novel design into operational reality***

Science Based Design & Testing



Innovative and Elegantly Simple Design

We followed the physics - letting the reactor run itself

By combining Heat pipe technology and solid fuel – our reactor designs are;

- *Simple*
- *Compact*
- *Lightweight*
- *Reliable*
- *Efficient*
- *And self-regulating through fundamental physical changes*

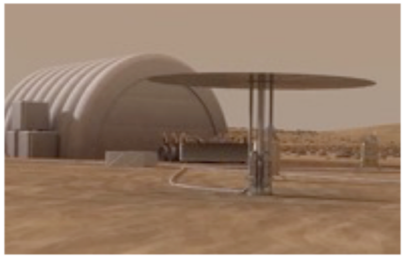
Jim Bridenstine @JimBride... · 2h
I'm impressed by the work @NASAglenn engineers are doing on the power systems that will enable us to explore, work and live on other worlds. Kilopower and Radioisotope Power technologies are unlocking tremendous potential for @NASA to go further.

LANL's reactor design was taken critical during LANL/NASA experiments at the Device Assembly Facility (DAF) in Nevada:
The design and the underlying physics have been validated.

LANL Special Purpose Reactors - Key Features

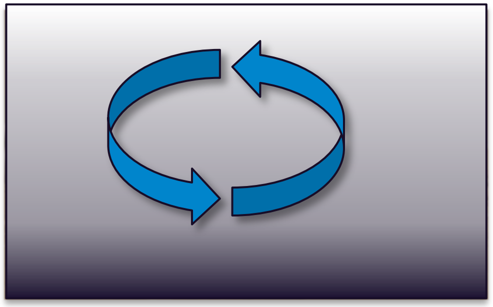
Heat pipes

- No pumps or complicated loops
- Highly reliable and safe
- LANL patent technology



Portability and lifetime

- Low mass / minimal volume
- MW for about 10 years (MegaPower)
- kW for about 10 years (KiloPower)
- No refueling

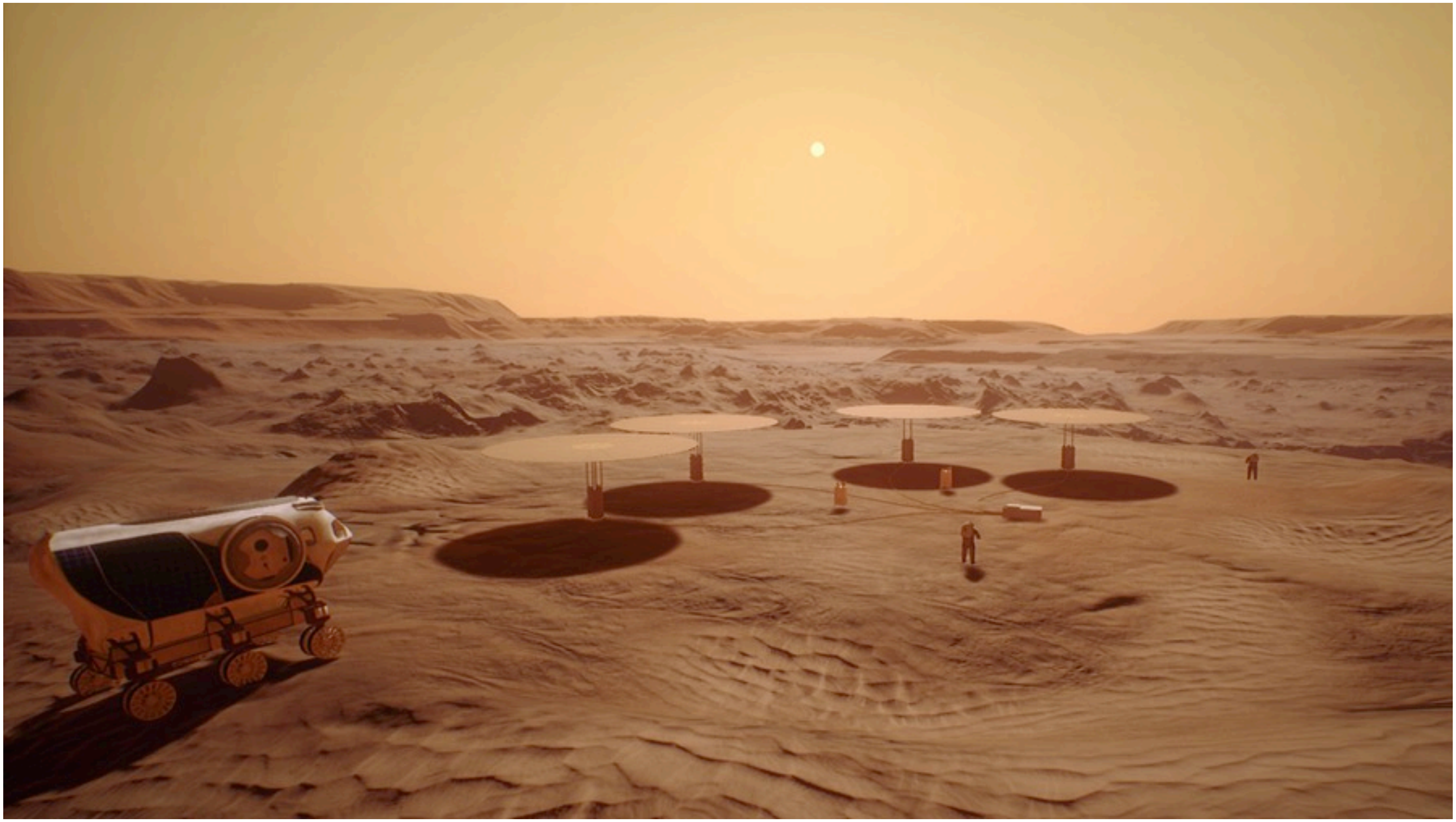


Self Regulated

- Autonomous options
- Immediate shutdown and passive cooling
- Thermally regulated, no need for active controls
- Load following (reactor self adjusts to power demand)
- Ease of operation in remote locations

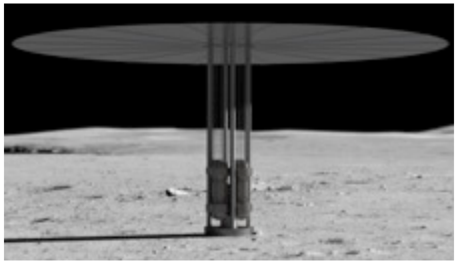
The Future?

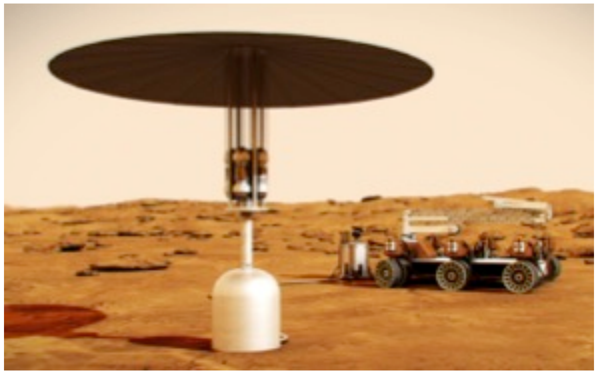
Reactors on Mars – NASA Concept



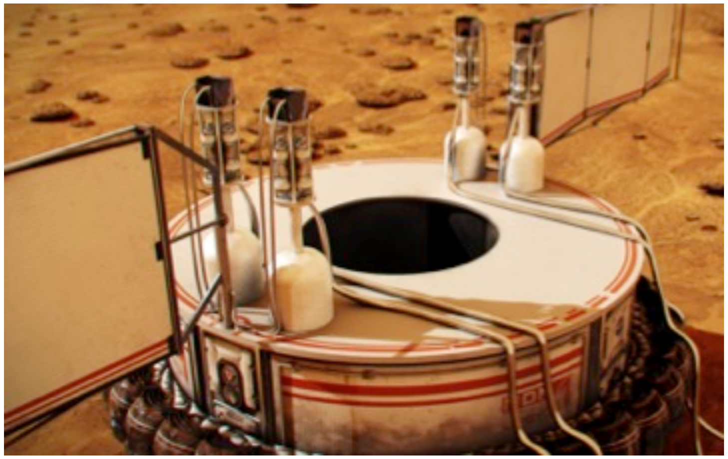
Picture – NASA Glenn Research

1 to 10 kWe Kilopower Surface Reactors





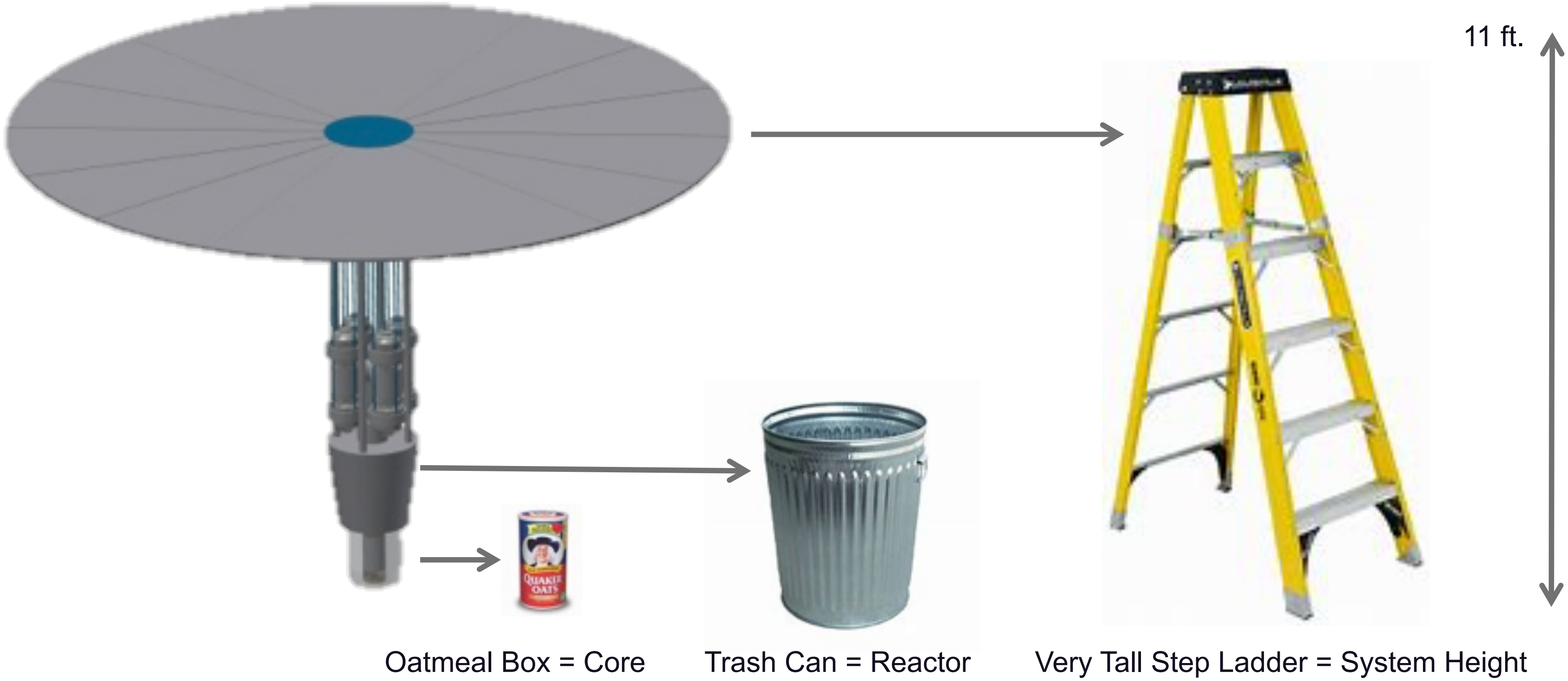
10 kW: 1500 kg



- Use multiple 10 kWe units for human missions
- Utilizes a deployable radiator
- Buried configuration at Lunar and Mars surface
- Full shield for lander configurations

How big is Kilopower?

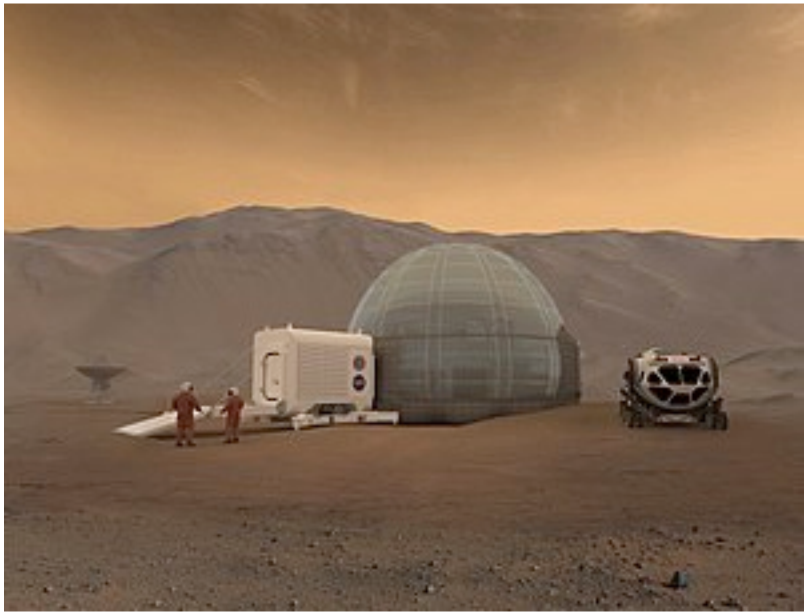
10 kilowatt electric Kilopower reactor



What is needed for Humans to go to Mars

- **Electricity would be used to make:**
  - Propellant to get back to Mars orbit
    - Liquid Oxygen
    - Methane

International Mars Research Station – Shaun Moss



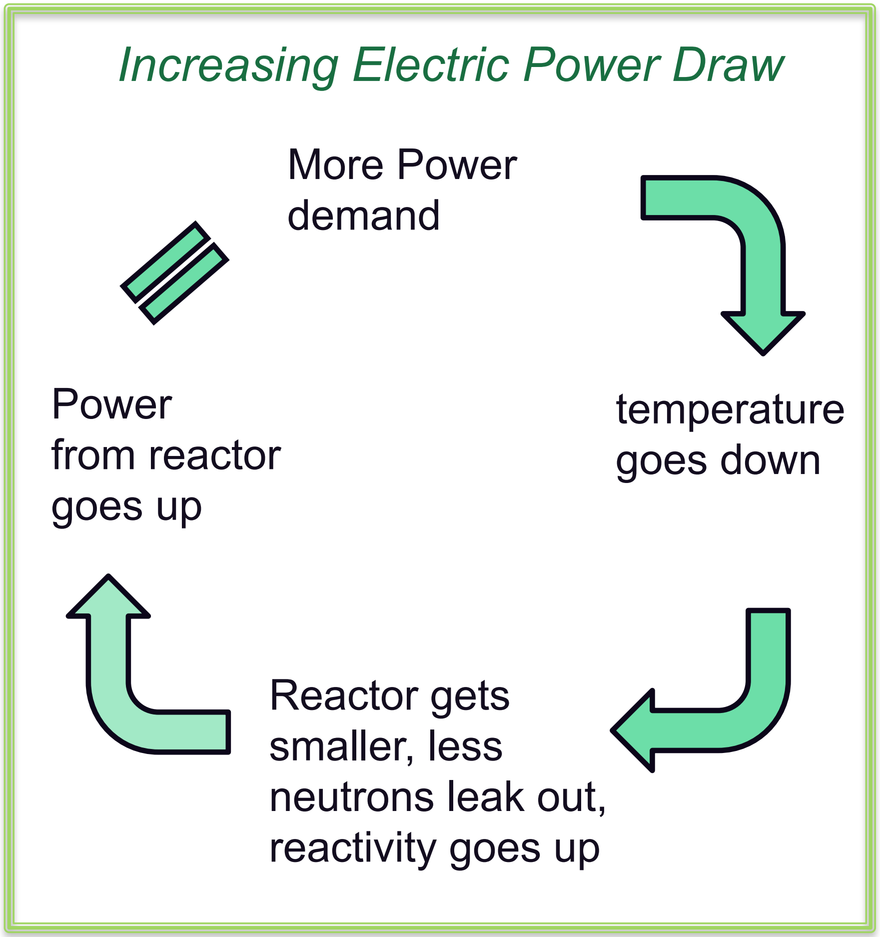
Mars Base Camp – NASA Langley

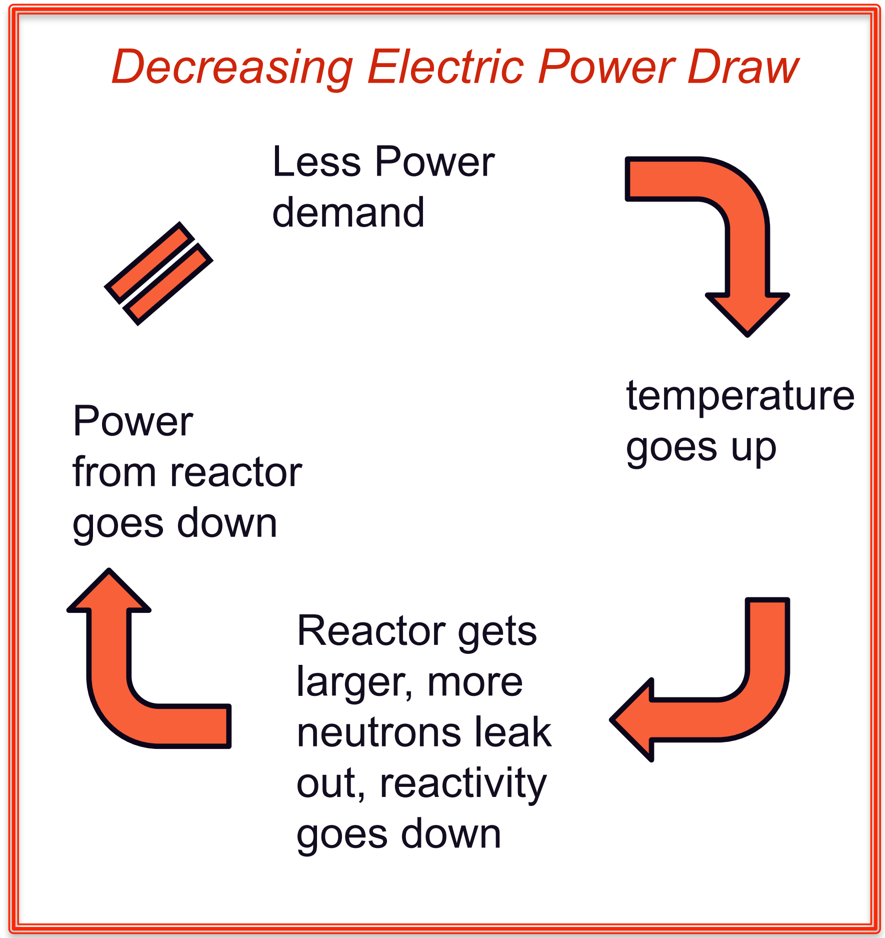
- **Electricity is needed for:**
  - Oxygen for astronauts
  - Purify water
  - Power of habitat and rover

Why this reactor design?

- **Very simple, reliable design**
  - Self-regulating design using simple reactor physics
  - The power is so low there should be no measurable nuclear effects
  - Low power allows small temperature gradients and stresses, and high tolerance to any potential transient
- **Available fuel with existing Infrastructure**
- **Heat pipe reactors are simple, reliable, and robust**
  - Eliminates components associated with pumped loops; simplifies integration
  - Fault tolerant power and heat transport system
  - The only reactor startup action is to withdraw reactivity control
- **Systems use existing thermoelectric or Stirling engine technology and design**
- **Low cost testing and demonstration**
  - Non-nuclear system demonstration requires very little infrastructure and power.
  - Nuclear demonstration accommodated in existing facility, the thermal power and physical size fits within current activities at the Nevada National Security Site.

Self Regulating Reactor



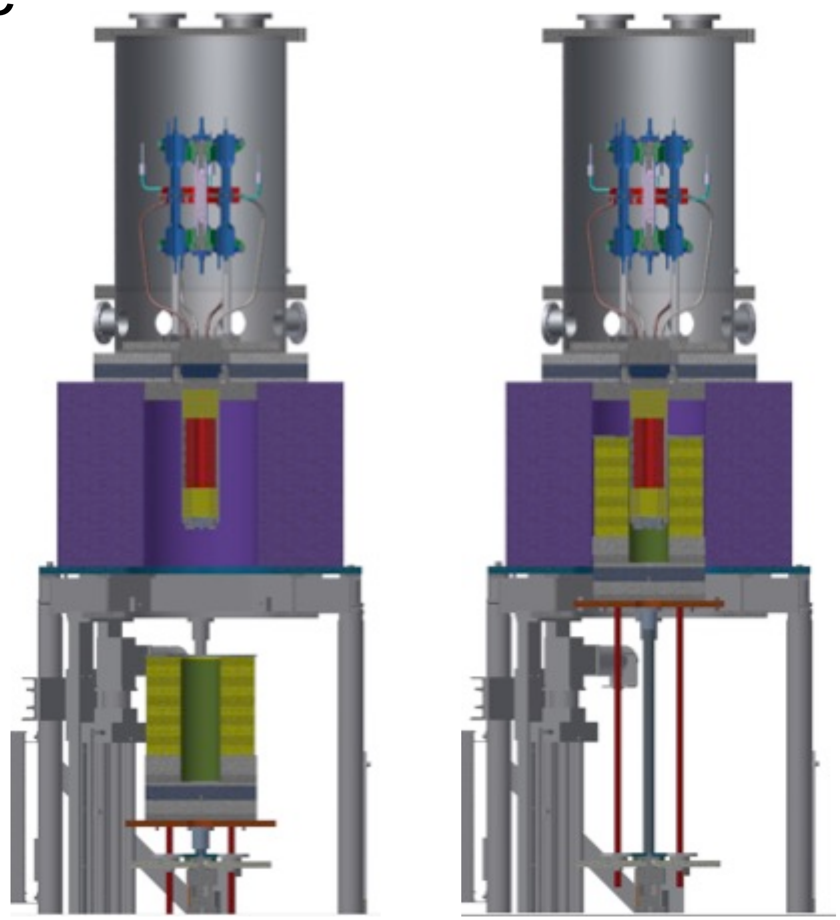


Space Reactor Safety

- **A reactor that has not undergone fission, (been turned on), has very very low safety concerns. It will have from 1 to 10's of curies of naturally occurring radioactivity**
- **This is 1,000s to 10,000s times lower radioactivity than in current radioisotope systems already flown in space**
- **Launch accidents will have consequences <u>100's of times less</u> than background radiation or radiation from a commercial plane flight**
- **After the reactor has fissioned, it will become radioactive**
  - Reactors would only be used in deep space, very high Earth orbit (long term decay) and on other planets.

Kilopower Reactor Using Stirling TechnologY = KRUSTY – Nuclear Demonstration Experiment

- Designed with space flight-like components
  - Uranium core, neutron reflector, heat pipes, Stirling engines
- Tested at flight-like conditions
  - In a vacuum
  - Design thermal power
  - Design temperature
  - Design system dynamics
- Performs tasks needed for space flight
  - Computer modeling
  - Nuclear test operations
  - Ground safety
  - Transport and assembly



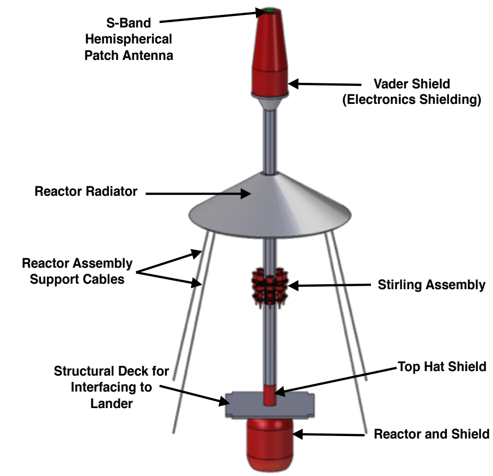
Experiment Assembly

KRUSTY Performance Metrics

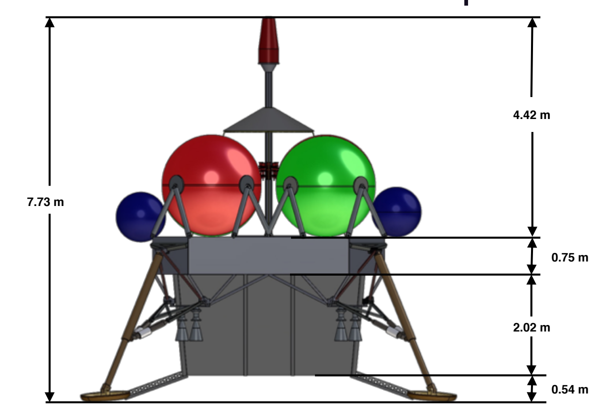
Event Scenario	Performance Metric	KRUSTY Experiment	Performance Status
Reactor Startup	< 3 hours to 800 deg. C	1.5 hours to 800 deg. C	Exceeds
Steady State Performance	4 kWt at 800 deg. C	> 4 kWt at 800 deg. C	Exceeds
Total Loss of Coolant	< 50 deg. C transient	< 15 deg. C transient	Exceeds
Maximum Coolant	< 50 deg. C transient	< 10 deg. C transient	Exceeds
Convertor Efficiency	> 25 %	> 30 %	Exceeds
Convertor Operation	Start, Stop, Hold, Restart	Start, Stop, Hold, Restart	Meets
System Electric Power Turn Down Ratio	> 2:1 (half power)	> 16:1	Exceeds

Current Work

- Project needs a <u>technology demonstration mission</u>
- NASA is looking at a reactor on the moon to power an ISRU unit (make propellent)
- Development work on Kilopower system and components is continuing

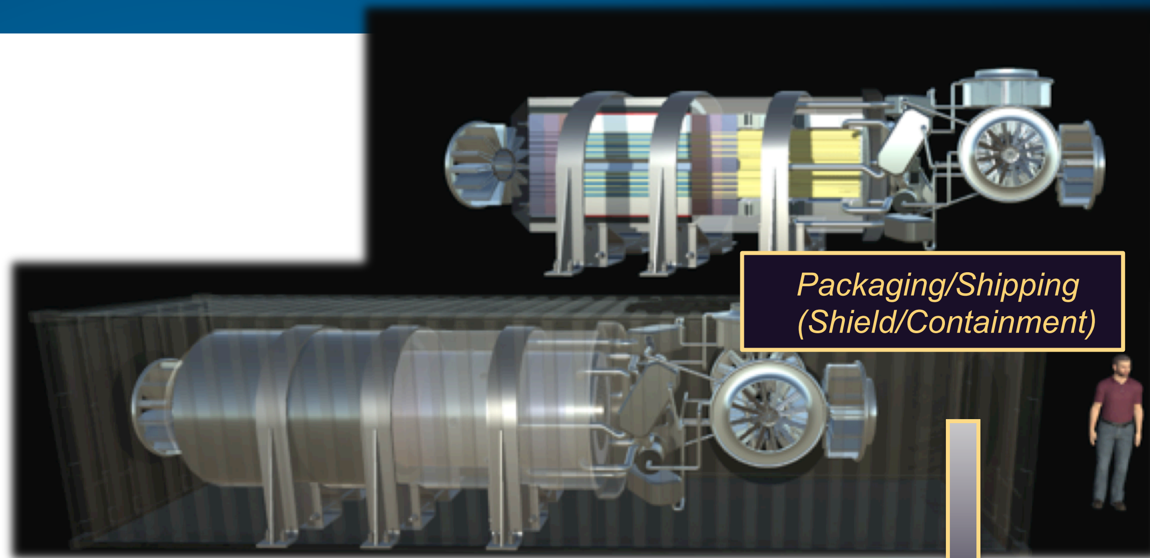


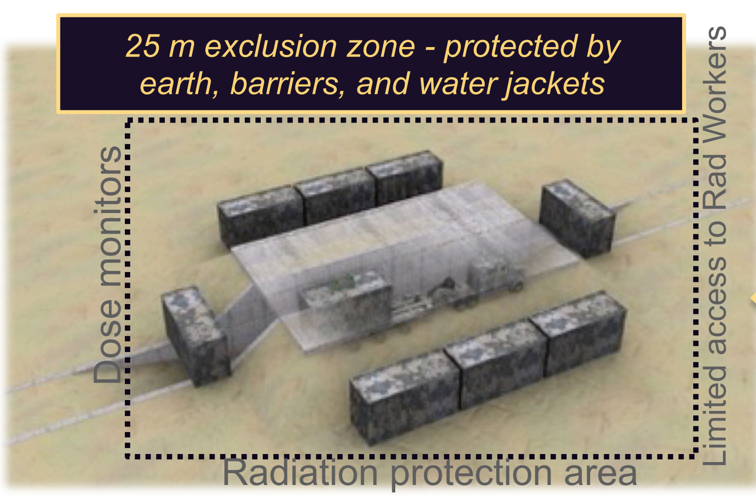
Lunar Lander Concept



Agile Military Power (AMP) – multi-MW Class Reactor
Following the physics to the next level

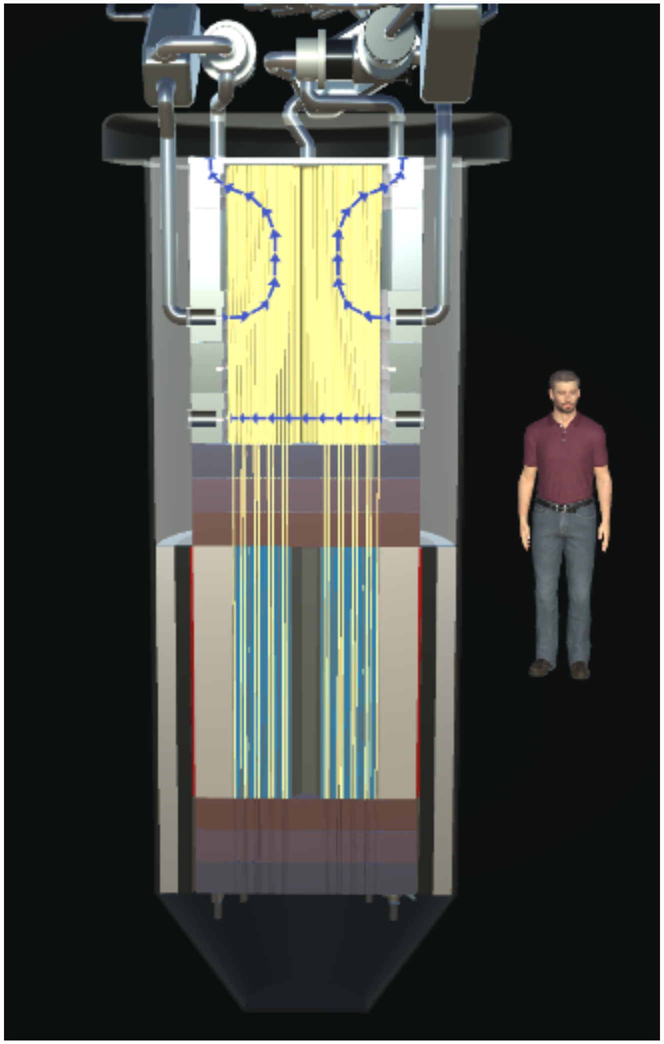
- Transportable by C-17/C-130 **aircraft** (Type C container)
- Transportable by **truck** to base
- Installed and **operating within 72 hrs**
- Easily Integrated to base, **no major civil structures necessary**
- Shutdown, cool down, disconnect and **“bug-out” in less than 7 days**





General Specifications of the AMP Design

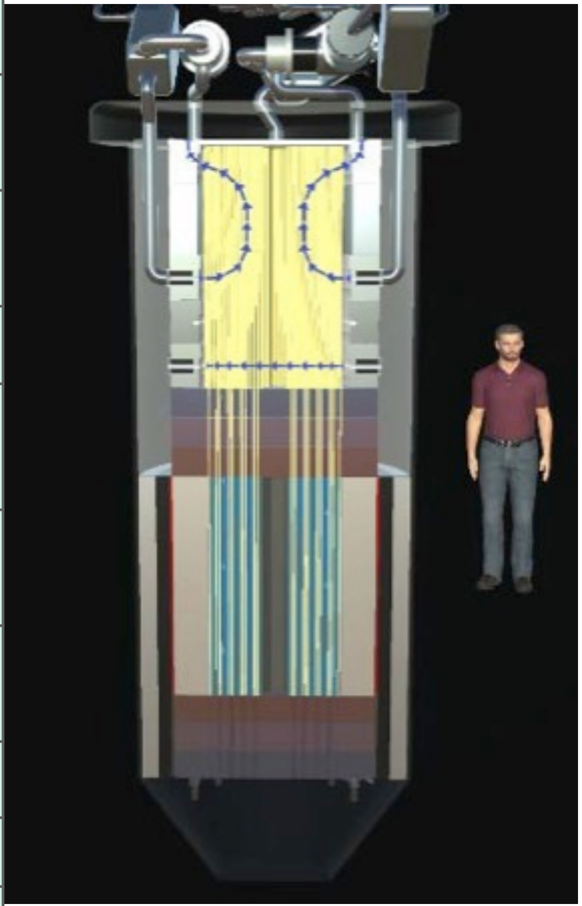
- **Fuel & Moderator:** 1,000-5,000 kg (UO_2/UN; U-Mo)
- **Power level:** Scalable ~1MW - 15 MW; 10-12 year life time
- **Monolith/Cartridges:** 10,000 kg (Core + Heat Exchangers)
- **Reflector:** 2,000 kg (BeO) or 8,000 kg (Al_2O_3)
- **Neutron and Gamma Shield:** < 12,000 kg (B4C + Pb/Steel)
- **Total weight:** ~35 metric-tons (~25 metric-tons for 2 MWe)
    - ~50% reactor and PCS
    - ~50% armor and shielding



Strong ceramics and metals serve as armor and shielding

AMP Key Design Features

Key Performance Parameters from DARPA Study	LANL Design Addresses KPP?
KPP1: Seamless multi-modal transport of the fresh and used reactor system	Yes
KPP2: No significant consequences from the design basis threats	Yes
KPP3: Transportable by C-17 aircraft (Type C container)	Yes
KPP4: Installed and operating within 72 hrs.	Yes
KPP5: Shutdown, cool down, disconnect and "bug-out" in less than 7 days ('should not be long-pole in the tent')	Yes
KPP6: Capable of immediate shutdown and passive cooling	Yes
KPP7: No significant increase in risk to the military personnel or to the environment	Yes
KPP8: Greater than 2-year refueling	Yes (>10 yr)
KPP9: Minimal proliferation risk	Yes (LEU)
KPP10: Design scalable to 10 MWe	Yes



KPP 1: Seamless multi-modal transport (fresh and used)

Factory Fabricated Reactor 'Block'

Packaging/Shipping (Shield/Containment)

"Plug-and-Play" on-site PCS assembly (CO_2 Brayton shown)

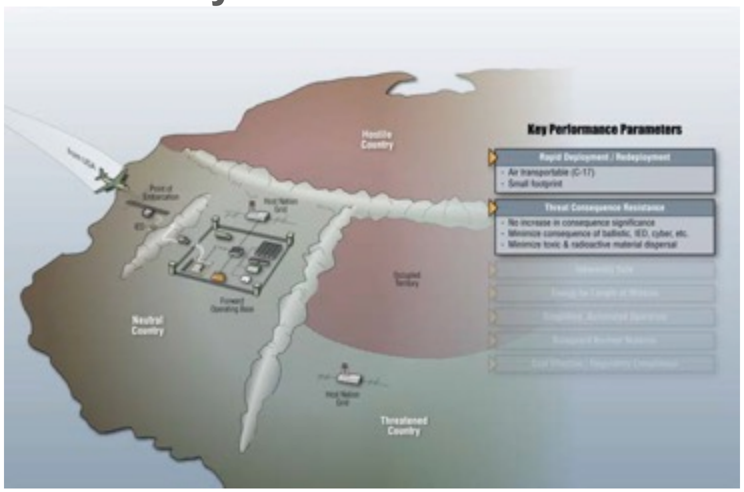
KPP 3: Transportable by C-17

Weight and form factor make C-17 transport possible for multi-MW versions of AMP

Weight and form factor make C-130 transport a feasible option for ~1 MW versions of AMP

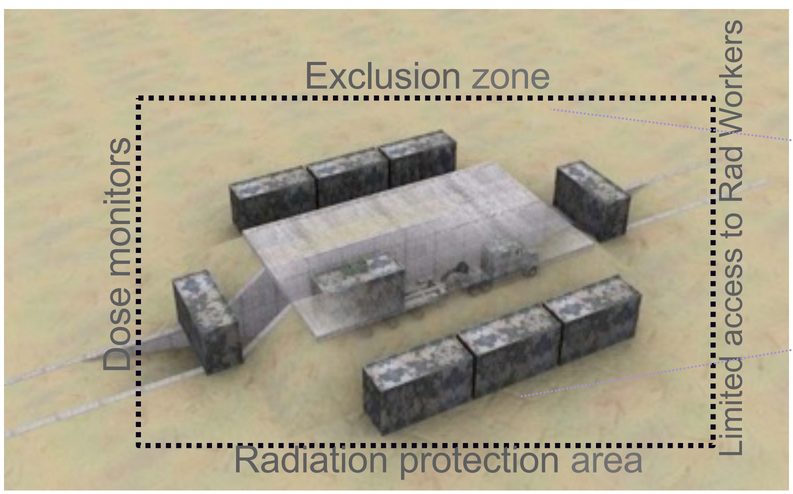
KPP4: Installed and operating within 72 hours

Fly reactor to theater

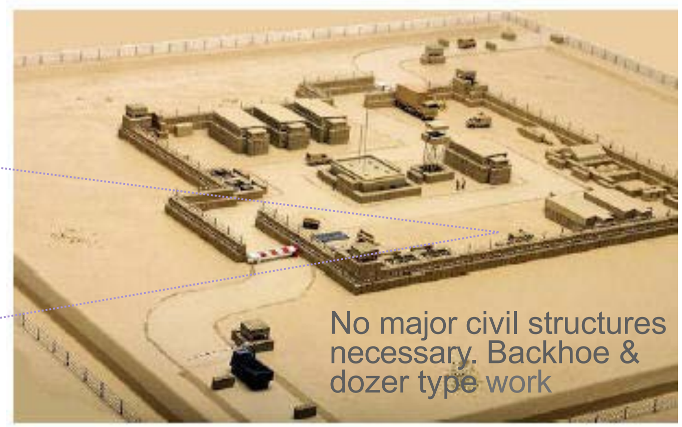


Transport by truck to the base

Protect by earth, barriers, & water jackets



Integrate into the base



Summary

- LANL is leading the efforts to develop micro-reactors
- NASA is looking to put reactors back into space as early as the mid 2020's
- LANL is working with industrial partners for DoD applications that could lead to commercial micro-reactors